EFFECT OF ALTITUDE ON SHORT TERM MEMORY

by

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To my daughter, Rachel,

the reason I went back in school.

ABSTRACT

Previous work has documented that cognitive deficits were observed in subjects tested at high altitudes (15,000 ft to 25,000 ft). Controversy remains as to whether cognitive deficits are observed at altitudes below 15,000 ft. The present study focused on this controversy, looking at the effects of moderate altitudes, 12,500 ft and 15,000 ft, on short term memory and compared them to a control altitude of 2,000 ft. Subjects were 72 students and instructors from the Department of Aviation Sciences at the University of North Dakota. After a series of pretests, including the Vocabulary Subtest of the Wechsler Adult Intelligence Scale-Revised, the Digit Span subtest from the Wechsler Memory Scale-Revised, the Vandenberg Mental Rotation Test, the Digit Symbol subtest of the Wechsler Adult Intelligence Scale-Revised, and the near-contrast sensitivity portion of the Vistech VCTS 6000 chart, subjects were assigned to one of three altitude groups and spent an hour and a half at their designated altitude for cognitive testing. One of the tasks administered was the Sternberg (Salthouse & Somberg, 1982) memory task. The second task was a dual attention task in which subjects performed a 30 min vigilance task while simultaneously listening to an audio tape with instructions to recall and read back a radio call prefaced by their assigned call sign. The audio tape of the radio calls contained four different call signs and half of the radio calls were high memory loads (at least 4 pieces of information) and half were low memory loads (no more than 2 pieces of information).

Analysis of variance was used to analyze the data. No consistent and interpretable effects were found in the Sternberg task. No effects of altitude were found in the vigilance task. The analysis of the readbacks revealed no significant difference for readbacks with low memory loads. However, for recall of readbacks with high memory loads, significant deficits in recall observed at 12,500 ft and 15,000 ft.

CHAPTER I

INTRODUCTION

Hypoxia, also known as altitude sickness, is a deficiency of oxygen in the blood. Although there are a variety of situations which can lead to hypoxia it is most often associated with high altitudes and thus is of special concern to the field of aviation. Aviators often fly at altitudes well above those where hypoxia can occur, and it is important for them to know what their symptoms are and when they are most likely to encounter hypoxic situations. Although symptoms vary from person to person, they often include headache, dizziness, nausea, a feeling of fatigue and an inability to concentrate. In more severe hypoxic situations, vision can be severely impaired, cognitive processes and, thus, performance are reduced and loss of consciousness can occur. If nothing is done to increase the oxygen level in the blood, death is possible. The two main focuses of this study are at what altitude do these performance decrements occur and what exactly are the cognitive processes affected.

The field of aviation accepts 3049 m (10,000 ft) as the level where physical and cognitive decrements due to hypoxia occur. However, studies are inconclusive. For example, Fowler, Paul, Porlier, Elcombe, and Taylor (1985) ran two similar experiments, one in which SaO2 (arterial oxyhemoglobin saturation) level was held constant and one in which it was allowed to vary. To induce hypoxia, subjects used a breathing apparatus which controlled SaO2 levels through various mixtures of O2 and

nitrogen. SaO2 levels were measured with an ear oximeter and continuously recorded. Both experiments used the mannikin task. In this task, subjects were shown a warning slide with either a blue or orange disc. Later, a mannikin was shown in one of four orientations, either upright or upside-down and front or back facing, and holding a blue paddle in one hand and an orange paddle in the other. Subjects had to decide in which hand the mannikin was holding the paddle that corresponded to the color of the disc on the warning slide and press the correct button on the handle bars of the exercise bike they were seated on. Reaction time latency from the presentation of the mannikin slide to the pressing of the button was recorded. Subjects in both experiments rode a bicycle ergometer, holding a constant workload by pedaling so the pointer of the bicycle's tachometer was held at a designated mark, to simulate pilot workload. In the first experiment, subjects were 32 student volunteers, ranging in age from 19 to 32. Hypoxia was induced by inhalation of gas mixtures, and SaO2 levels were held constant, between 88 to 90% (equivalent to 2438 m or 8,000 ft), by constantly monitoring subjects' SaO2 levels with an ear oximeter and adjusting the mixture of oxygen and nitrogen they were breathing. The induction and stabilization of hypoxic conditions took 20 min which was followed by the four blocks of slides. After completion of the task, subjects were given a 10 min rest period before performing the task under non-hypoxic conditions. In Experiment 1, speed was emphasized more than accuracy and data were collected in two different lighting situations, high-luminance and low-luminance. Both error rate and reaction time data were collected. Analysis of the error data revealed that breathing the hypoxic mixture did not affect error rate. Analysis of reaction time data also did not

reveal any important difference between breathing hypoxic mixtures and air. In sum, the results showed no decrement in performance under the experimental hypoxic conditions.

In the second experiment 20 subjects from the same pool participated in a conceptual replication of the same procedures. This time subjects performed the task only once, either while breathing the hypoxic mixture or while breathing air. The procedures were the same except that a normally illuminated room was used and, for the hypoxia group, after initial stabilization of SaO2 level between 88% and 90%, SaO2 level was allowed to vary. In this part of the study, SaO2 level dropped and the reaction time data revealed an increase in reaction time latency, but the hypoxic conditions induced by the breathing apparatus may be different from that which one might experience under flight conditions. To better understand this difference and to better understand why SaO2 levels dropped, the bike used in Experiment 2 was placed in an altitude chamber and 6 subjects performed the pedaling task while breathing chamber air. None of the subjects showed a clear drop in SaO2 level. This suggests that the drop in SaO2 levels in experiment two was due to a combination of hypoxia, workload and, mostly, an increase in breathing resistance caused by the apparatus used to induce hypoxia. No reaction time data was collected in the chamber. Overall, these results did not support the study it was meant to replicate, the one by Denison et al. (1966) who reported an increase in reaction times at 2438 m (7,996 ft) in a hypobaric chamber with subjects performing the mannikin task while peddling a bicycle ergometer at a constant workload.

Fowler, Elcombe, Kelso, and Porlier (1987) also induced hypoxia via a breathing apparatus. In this study, 6 volunteer subjects, 3 men and 3 women, were paid to

participate. The subjects were exposed to various mixtures of oxygen and nitrogen, designed to reduce the level of SaO2 to the range of 86% (equivalent to 8900 ft) to 76% (equivalent to 11,400 ft). The SaO2 levels tested were 86%, 84%, 82%, 80%, 78%, and 76%, and each SaO2 level was tested in one session only, for a total of six sessions, each at least 1 day apart. For the first 3 subjects, order of oxygen level was random. For the next 3, a descending order from 86% to 76% in 2% increments (500 ft) was used and two additional sessions were performed at 84% and 82%. The task required subjects to press, with a wand (30 cm long), a disc adjacent to an illuminated light emitting diode (LED). Stimuli were presented at both high and low brightness levels, counterbalanced across sessions. Each session was about 60 min long with the first 20 min dedicated to visual acclimatization to the brightness level before response tests were started. A computer measured the time from illumination of the LED to the response and also the number of lights that were not responded to. The response times were measured in each session first for breathing air, then the hypoxic mixture, then air again. Data from the various sessions were pooled. Analysis showed response time (RT) was not effected at 86% and 84%. However, at 82% (9,500 ft) both high and low brightness conditions reflected a decrement in performance, with the effects being slightly greater for the low brightness condition. There is a possible error in oxygen content of +/- 1%. Therefore, 83% (9750 ft) was established as the threshold for perceptual-motor decrements due to hypoxia, which could be at least partially due to visual impairment brought on by the lowered oxygen level.

Fowler, Prlic, and Brabant (1994) manipulated SaO2 levels in another study involving two separate experiments. Twelve subjects for each of the two experiments

were selected from the Defense and Civil Institute of Environmental Medicine and York University. Hearing was tested for those in experiment one, and sight for those in experiment two. Hypoxia was induced by breathing an O2 mixture and maintaining SaO2 level 64-66% (13,900-14,400 ft). Half of the subjects in each experiment breathed air followed by the hypoxic mixture while the other half did the opposite. SaO2 levels were stabilized after approximately 20 minutes of breathing the mixture, and the same amount of time was allowed for recovery from hypoxia before testing in the normoxic condition. All subjects were tested under both conditions, on the same day, in a single session with the session being approximately 45 min for Experiment 1 and 55 min for Experiment 2. All subjects were given practice trials on the tasks. Two separate experiments were performed. In experiment one, subjects participated in a dichotic listening task that consisted of 10 sets of 4 pairs of random digits. The digits were recorded at the rate of two pairs per second, followed by 9 s of silence. Subjects were told to attend to the data in one ear and to write down the digits in order from the attended ear first and then from the other ear. Previous work by Bryden (1964) and by Fowler, White, Wright, and Ackles (1980) with this task has found that recall from the attended ear is high, but recall from the unattended ear drops rapidly as a function of digit serial position. The assumption is that material presented to the attended ear is immediately processed while the unattended ear material is stored in short term memory prior to processing. The task is used as an assessment of the rate of decay of information from short term memory. The authors examined whether the rate of decay of the unattended ear digits was greater under

hypoxic conditions. The results indicated that hypoxia decreased recall but the effect was equal for both ears, indicating no short term memory storage deficits.

In experiment two, subjects performed a memory scanning task, the Sternberg task. Memory sets of 2, 4 or 6 digits were displayed for 2,000 ms on a computer screen followed 300 ms later by a probe digit which was displayed for 1,398 ms. Subjects had to decide whether the probe digit was a member of the memory set. Each set size was presented in random order and consisted of 15 positive probes and 15 negative probes. The slope of the line relating reaction time to set size is used as an estimate of the rate of short term memory scanning. The results indicated that, although response time significantly increased with hypoxia, the slope of the line relating memory set size to response time was not significantly different between the hypoxia and control groups. Therefore, the authors concluded that the rate of scanning short term memory was not impaired at SaO2 levels of 65%. No other interaction effects were significant.

The primary result of these studies was that hypoxia did not affect the rate of decay of information from short term memory or the rate of scanning for information in short term memory.

One potential limitation of the previous three studies is the question of what is the effect of the resistance caused by the breathing apparatus. For instance, Fowler et al. (1985) noted that breathing resistance while using the breathing apparatus was five times higher than normal breathing resistance, possibly having a significant contribution to the drop in SaO2 level. Paul and Fraser (1994) removed the influence of this variable by using a hypobaric chamber. Subjects were 144 volunteers, ages 19 to 25, from the Canadian

Forces. None had any experience in a hypobaric chamber. Subjects were randomly divided into 16 groups and assigned to one of four altitudes, 1,525 m (5,000 ft), 2,440 m (8,000 ft), 3,050 m (10,000 ft), or 3,660 m (12,000 ft). Each subject was tested on three tasks, given in random order. Half of the subjects were tested at sea level and then at altitude while the other half were tested at altitude first, then at sea level. Sessions lasted approximately 30 min with at least 1 hr between sessions so both hypoxic and normoxic conditions occurred in the same day. Decompression took place at the rate of 1,500 m per min. For sea level tests, subjects were brought up to 1,525 m and then let down at a rate they believed the subjects would not be able to perceive. Subjects were at altitude for a least 5 min before starting any test. All subjects were tested while seated on a exercise bike, half of whom were actually peddling. Three separate tasks were employed in this experiment, the Spatial Orientation Task (SOT), the Logical Reasoning Task (LRT), and a Serial Choice Reaction Time Task (SCRT). The SOT used was the mannikin task which has already been described. A block of trials for this task was made up of all 16 possible combinations and four blocks were given in each of the two sessions. The LRT used (Baddeley, 1968) was a pencil and paper test. Subjects read a sentence such as, A is before B, A is after B, A is not before B, and A is not after B. Each sentence was followed by a pair of letters, AB or BA. If the sentence described the letter pair, true was marked. If not, false was marked. Subjects were told to go as quickly as possible with out making errors and were given 30 s between blocks. The number of correct responses was recorded. There were 32 possible combinations randomly organized on each of 16 pages. A block was one of these pages and four blocks were given in each of the two

sessions. The SCRT task used consisted of five push buttons arranged in a pentagon shape on a flat-black background. Next to each button was a red light emitting diode (LED). When the LED was illuminated, subjects used a 30 cm long stick to press the corresponding button. Time from LED illumination to pressing the button was recorded by computer. Subjects were told to go as quickly as possible without making errors. A block was 1 min worth of trials. Again, four blocks were performed, with 30 s between blocks in each of two sessions. Subjects were also continually physiologically monitored for respiratory frequency, Po2, Pco2, both taken from the subjects at each breath, and SaO2 levels, monitored by an ear oximeter. Result did not confirm the hypothesis that hypoxia affected the learning of a naive subject. In the SOT and SCRT, subjects performed better on their second trial, whether at altitude or sea level, showing that learning had taken place irrespective of altitude. Subjects performed better on SOT and LRT while resting as compared to exercising, reflecting a main effect of exercise on performance. However, exercising subjects, who showed lower SaO2 levels and, thus, higher hypoxic levels, performed better on the SCRT than their resting counterparts, reflecting the opposite of hypoxic-induced performance decrements. There was a reaction time advantage for those who performed the SCRT at sea level first which could be accounted for by the minimum variability for the data for this test. For the LRT, subjects did better at 8,000 ft than at 5,000 ft, 10,000 ft, or 12,000 ft and continued to get faster with altitude from 8,000 ft to 12,000 ft, again showing no effects of hypoxia on performance. Exercise had a significant effect on all four of the physiological parameters measured, as well as a significant interaction with altitude and order of presentation,

affecting Po2 and Pco2. After exercise at 12,000 ft, subjects showed an increase in Po2, possibly reflecting a compensatory increase in ventilation.

Kennedy, Dunlap, Banderet, Smith, and Houston (1989) also simulated high altitude conditions in a hypobaric chamber. They used 8 subjects who were chosen because of their motivation, interest, age, and general physical condition and who ranged in education level from no college experience to M.D. The subjects lived in the chamber for 40 days during which a slow ascent to 8,845 m (29,000 ft) was accomplished. For this study, tests were selected from the Automated Performance Test System (APTS) which contains tests that tap diverse sensory, cognitive and motor functions. These tests included the Sternberg task to assess short-term memory, the Nonpreferred Hand Tap, Two-hand Tap, and Preferred Hand Tapping tasks to assess manual dexterity, the Pattern Comparison task to assess pattern recognition, the Code Substitution task to assess memory association perceptual speed, and the Grammatical task to assess logic and reasoning. Although none of the tasks were explicitly explained in this article, the analysis for the Sternberg task, which only shows one measure for this task, the change in performance as the percent correct, suggests that the Sternberg task used only a single set size. Normally, in this task, a range of set memory set sizes is used, and subjects study the memory set which is followed by a probe and must decide as quickly as possible without making errors if the probe is a member of the memory set. The slope of the line relating reaction time to set size is used to estimate the rate of short term memory scanning. This slope cannot be calculated from the data collected by Kennedy et al. A similar lack of information pertains to the rest of the tests used here. All tasks were practiced nine times

before ascent but not in the chamber. It is stated that, under experimental conditions, since acclimatization was investigated in this study, subjects were at an altitude for 2 to 3 days before behavioral testing. Cognitive and psychological measures were not obtained above 7,625 m (25,000 ft). The purpose of this study was to examine changes in cognitive and motor functions during exposure to hypoxic conditions. Subjects were tested at 60m (200 ft), 1,220 m (4,000 ft), 2,290 m (7,500 ft), 3,360 m (11,000 ft), 4,575 m (15,000 ft), 5,490 m (18,000 ft), 6,100 m (20,000 ft), 6,250 m (20,500 ft), and 7,020 m (23,000 ft), and were tested twice at 7,625 m (25,000 ft). A baseline performance altitude of 4,575 m (15,000 ft) was established and performance at all other altitudes was compared to it. This altitude was chosen because it was the altitude at which experimenters stopped entering the chamber, creating more standardized conditions. The data were analyzed by calculating a performance drop index each task. This was done by averaging the 2 scores at 7,625 m (25,000 ft) and comparing it to the average of scores at 4,575 m (15,000 ft) and below. For the Sternberg task, the number of items scanned decreased and the time per response increased as altitude increased, especially at 7,625 m (25,000 ft). The performance drop index showed a drop of 20.8%. The effects on the Pattern Comparison task were dramatic. The number correct began dropping and response time began rising by 7,015 m (23,000 ft), and were clearly impacted by 7,625 m (25,000 ft), with performance dropping 30.2%, accounted for mostly by a decrease in reaction time with the error rate remaining constant. The Code Substitution task was not severely effected. Performance dropped only 14.5%. There was a significant effect on the number correct but this task could be performed by some subjects even at 7,625 m

(25,000 ft). The Grammatical Reasoning test showed the most dramatic and consistent declines, with a performance drop of 46.5%. None of the three tapping performance measures showed significant differences. Performance on the Pattern Comparison and Grammatical Reasoning tasks show that every subject was impacted by 7,625 m (25,000 ft). However, on the Sternberg and Code Substitution tasks, only certain subjects showed a dramatic drop at the same altitude. This may suggest that the altitude of 7,625 m is a threshold for impairment of cognitive functions tested by these two tasks. These findings suggest that the Pattern Comparison and Grammatical Reasoning tasks are adequate predictors of the diminishing capacity at an altitude of 7,625 m (25,000 ft) and that this altitude is a threshold for the capacities tapped by the Sternberg and Code Substitution tasks. The three manual dexterity tasks were not significantly affected at any altitude.

Two main points can be taken from this study. First, human performance decrements occur under these experimental conditions and cognitive disruptions are more prevalent than motor disruptions, although the two may not be totally separate. Second, this study shows a battery of simple and efficient tests that evaluate different aspects of performance, those being cognitive and motor aspects.

There are three procedures pointed out in this article which may have affected the results. First, practice sessions were not held in the chamber. This different setting could confound the results. Second, during the experiment, some subjects delayed task administration if they were too severely affected by altitude which could lead to an underestimate in the effects of altitude. Finally, subjects were enduring a battery of physiological tests while in the chamber. This may have adversely affected performance

on the non-physiological tasks by creating a distraction or even discomfort. One other major limitation is the repeated administration of the tasks, which, because of practice effects, could mask any hypoxia effects.

Another area in which hypoxia is a concern is mountaineering. Even though many factors, such as weather conditions and physical exertion, add to the effects of hypoxia, these studies are still of value to this current discussion. Jason, Pajurkova, and Lee (1989) conducted one such study. Subjects were 12 climbers, 11 men and 1 woman. All but 1 climber had previous experience in the Himalayas. All subjects were given a series of neuropsychological tests 1 to 3 weeks before the climb began and again 2 to 7 weeks following return to base camp. The post tests were completed on 9 of the original 10 subjects. The tests included Wechsler Memory Scale, Delayed Verbal Recall, delayed recall of a complex visual figure, Hebb Digits Sequence Learning, Corsi Blocks Sequence Learning, and Prospective Remembering. The Wechsler Adult Intelligence Scale was also used to measure the general level of intellectual ability. Ten of the climbers were administered a variety of tests at various altitudes. These tests included Trail-Making A and B (tracking and concentration), the Digit Symbol subtest of the WAIS-R, timed letter cancellation (Diller, 1974), and timed Star-tracing, all three of which assessed concentration and visuomotor coordination, and a grammatical reasoning test. Climbers also gave two estimates of 30 s time interval, with feedback after the first trial to see if they could adjust their estimate, and wrote their signature with each hand to assess motor coordination. All climbers were acclimated prior to their climb for 3 to 6 weeks by carrying supplies between 5,100 m (16,728 ft) and 6,000 m (19,680 ft). No more than 4

nights in a row were permitted at altitudes of 7200 m (23,626 ft) and above, and oxygen was used above 7500 m (24,600 ft) with the exception of 1 climber who ran out and spent 7 hr without oxygen until reaching camp at 8,230 m (26,994 ft). An examination of pre-climb and post-climb scores indicated no significant decrements in performance, and no clinical impairments were noted. In fact, some subjects showed significant improvement on some of the tests. Time at altitude and altitude climbed to did not show any significant correlation with changes in test results. The results of the tests taken during the expedition also showed little change. One subject showed an improvement on the letter cancellation task. There was a trend of fewer correct answers on the grammatical reasoning task at higher altitudes but the results were not significant. The total number of tests completed was small and acclimatization may have affected results. Practice effects and the duration of time from return to testing may have also affected the results.

Nelson, Dunlosky, White, Steinberg, Townes, and Anderson (1990) performed an experiment to examine the effect of high altitude (mountaineering) on the retrieval of previously learned information A second goal of this study was to examine the effects of high altitude on people's judgments about whether or not they could retrieve information from long-term memory. This self awareness is one component of metacognition, which is defined as monitoring and control over your own cognitive activities. Their subjects were 9 men and 3 women, all of whom were highly experienced climbers and had at least 2 years of college education. In this study, participants served as both subjects and experimenters, administering the tests to one another. The expedition was a climb up Mount Everest. Planned testing times and locations were 48 hrs after arrival in

Kathmandu (1,200 m or 3937 ft), 48 hrs after arrival at basecamp (5,400 m or 17,712 ft), 48 hrs after arrival at Camp 2 (6,500 m/ 21,320 ft), a second time at 6,500 m or higher at either Camp 2 or Camp 3 (7,100 m or 23,288 ft), at base camp after a climber attained his/her highest altitude, and again at Kathmandu approximately 1 week after return from camps. One subject stayed at basecamp so there was no high altitude data on him. Three subjects were not tested at basecamp before the expedition and one subject did not test a second time at high altitude. The stimulus materials used to test retrieval were 238 general information questions arranged on stimulus cards. The questions were broken down into 7 subsets of 34 items each and were equated on difficulty level. Subjects were blindfolded and were then read all of the questions from a subset. They were given unlimited time to produce a response. Responses were recorded, noting if they were correct or if no guess was made. The second phase of the experiment measured Feeling of Knowing (FOK). Only the questions the subjects answered incorrectly in the first portion of the experiment were used in this portion. These questions were again read, and the subjects were asked to estimate, using a scale from 1 to 6, how likely they would be able to recognize the correct answer from the eight recognition alternatives which were provided for each question. The cards were shuffled and subjects again rated the questions in the same way. Finally, the blindfold was removed and subjects had a forced-choice recognition test again using only the incorrect items and using the eight alternatives provided. Three measures of retrieval were obtained from this task, percent correct recall of answers to general-information questions, latency of correct recall, and percent correct recognition of nonrecalled answers. None of these measures showed any deficits at any

altitude. The FOK measures, however, were affected by altitude. A median FOK was computed for each subject at each altitude and comparisons were made between them. The results showed that, although there was no significant change between scores at the first testing at Kathmandu and at base camp or between the last three sets of scores, there was a significant decline in the median FOK between the first two administrations and the last three administrations. The overall results lead to the conclusion that there is no effect of altitude on retrieval of general information. However, altitude does effect one aspect of metacognition, the Feeling of Knowing, and this effect remains more than a week later when subjects were again tested at sea level.

Kramer, Coyne, and Strayer (1993) also performed a study involving the effects of high altitude (mountaineering) on cognitive performance. Two groups of 10 each were volunteers for a climb up Mount Denali in Alaska. Two additional groups of 10 each were used as control subjects and performed tests at the University of Illinois at Champaign-Urbana. Each of the four groups consisted of 9 men and 1 woman. Two sets of computer-controlled tests were used. One group of climbers and one of the control groups performed the category search task. Subjects were presented with either 2 or 4 category labels followed by 20 probe trials. Half of the probe trial were targets (an example of one of the targets) and half were not. Reaction time and accuracy were recorded. The second set of tests consisted of five tasks selected from the Automatic Performance Test System (APTS). The first task was a pattern comparison task which presented subjects on each trial with two spatial patterns of asterisks. The spatial patterns were generated by filling in a three (vertical) by six (horizontal) matrix with 3 to 12

asterisks. Subjects were required to decide as quickly as possible whether the patterns matched. This task was assumed to measure perceptual speed and spatial ability. The second task was a code substitution task in which subjects were shown a row of seven letters followed by a row of seven numbers. On each trial a letter was presented below the row of numbers and letters. The subjects responded with the number that corresponded to it. This task was assumed to measure perceptual speed and associative memory. The third task was a choice reaction time task in which subjects pressed an arrow corresponding to the location of a "+" sign appearing with equal probability at the top, bottom, left, or right portion of the screen. The task was assumed to measure response selection speed. In the fourth task, a memory search task, subjects memorized six letters and were given 10 probe trials during which they responded as quickly as possible to whether or not the probes were in the memory set. The subjects were then shown a new memory set of six different letters and repeated the task. A practice period of 60s was given followed by 240 s of experimental trials. This is assumed to be a measure of short-term memory. Finally, a finger-tapping task was given. Subjects used their index and middle fingers to tap as rapidly as possible between the K and L keys on a computer keyboard. This was assumed to measure motor speed and control. The climbers who took the APTS tasks were tested first at 92 m (3,028 ft), after which the climb up Mount Denali, which is 6194 m (20,316 ft) high, began. Climbers took 5 to 9 days to climb to Genet basin, the mountain testing station at 4,360 m (14,301 ft), and then spent several days carrying supplies to higher camps. Climbers then attempted to reach the summit and, after their attempt, the subjects in the APTS group were again tested, this time at Genet

basin. The time between the first administration of this battery of tasks and the second was 12 to 18 days. All of the climbers completed a physical symptoms checklist at this time. Finally, both groups of subjects were tested again after their return to 92 m (3028 ft), with the range of time from the first to last testing being 18 to 26 days and the time from return to lower altitude to retesting being 1 to 2 weeks.

Results of the pattern comparison task and the code substitution task revealed that controls responded more quickly than climbers but climbers' performance was stable across trials while control subjects improved with practice. The choice reaction time task showed that controls responded more quickly than climbers but there was no effect of practice. For the memory search task, controls responded more quickly than climbers at all three testing times and response speed increased across sessions for both climbers and controls. Finally the tapping task revealed no significant difference between any of the tests.

This experiment draws two main conclusions. First, high altitudes can have sustained effects on the performance with the deficit still being significant 1 to 2 weeks after the climb. Second, the use of a control group is imperative in this type of work. Otherwise, the present study would have erroneously concluded that altitude has no impact on performance.

Another mountaineering study was reported by Bonnon, Noel-Jorand, and Therme (1995). Six control and 6 experimental subjects, all physicians, participated in this study. The 6 experimental subjects had all climbed Mont Blanc at least once. The study's objectives were to look at the effects of hypoxia on a cognitive-motor task with heavy

attentional loading and to assess the general well-being of the subjects. All subjects were tested three times. The experimental group was tested first in the town or Chamonix at 1035 m (3,395 ft), then, after a 10 min helicopter ride to the Mont-Blanc Observatory, at 4,328 m (14,196 ft) 8 to 20 hrs after ascent, and, finally, after a 48 to 60 hr stay at the observatory. The control group was also tested three times, on three separate occasions, at the same time of day as the experimental group. They did only the cognitive-motor task and were under normoxic conditions. In the cognitive-motor task subjects were presented with a numeric code sequence for five letters. They were required to punch as quickly and accurately as possible into a calculator the correct number corresponding to the given letter. They were given six practice trials and the actual test consisted of 30 trials. The task has a sensorimotor component, finding the correct key and controlling the pressing action, and a cognitive component, proper identification, short-term memory encoding and planning. The interviews were conducted on the experimental subjects to assess their general well-being. Three questions were asked, answers were recorded, and three independent experimenters classified the statements as positive or negative.

The results show that, for the experimental group, there was a significant difference between the first administration of the cognitive-motor task and the second but not between the first and the third. The control group showed continued improvement throughout the task. The results of the task show that there is a difference in learning between the control group and the experimental group during their first hypoxia period. However, by the third trial performance differences are no longer significant. The interview results revealed a decline in general well-being between normoxia and the first

hypoxia period on all three questions and between normoxia and the second hypoxia period on questions one and three. For the first versus the second hypoxia period, only question 2 showed a significant difference. The article proposes two hypothesis to explain these results. "First, hypoxia may disturb the processes involved in executing this task, both at higher levels where actions are programmed and at lower levels where execution is achieved and controlled" (p. 334). Second, "the degraded well-being... may create a psychological state of self-concern as an adaptation to the stressful conditions. This psychological reaction may interact with the subject's physiological reactions... [which] may hinder the intake of the information required to carry out the task" (p. 334) The third administration of the task shows support for an adaptation period to hypoxia.

There are two major limitations to this study. First, doctors were used as subjects. Doctors tend to have high verbal skills and, therefore tend to be less sensitive to manipulations that cause cognitive deficits. This limits the generalizabilty of this study. The second limitation is that the time of acclimatization was confounded by practice. That is, subjects tested after a 48 hr to 60 hr stay at the observatory had already been tested 8 hr to 20 hr after their arrival. The practice effects may have covered up any effects that would have been brought about by acclimatization.

The Present Study

The purpose of the current study was to reexamine the effects of moderate altitudes on the short term memory of aviators. This experiment is important because previous studies had some shortcomings or have added variables which may not be relevant to aviation. For example, Fowler (1994), who concluded that hypoxia does not

affect working memory, had very few subjects in his study which does not allow for a powerful test of the effect of hypoxia. In addition, Fowler manipulated hypoxia as a within-subjects factor and reported no statistically significant carryover effects when allowing only 20 min to recover from hypoxia when testing controls. Possibly, the small number of subjects tested resulted in a very weak test of carryover effects when going from the hypoxia to the control condition, and this needs to be carefully considered in light of the work Kramer et al. (1993) and Nelson et al. (1990) who showed cognitive deficits days after exposure to high altitudes. However, the study by Kramer et al. examined the effects of hypoxia during a mountain climb which could mean that some of the affects were a result of factors other than hypoxia such as physical exertion and climate. Also, Fowler did not have a control group. Thus, he could not show the effects of practice as Kramer et al. did.

The present study used a short term memory scanning task by Sternberg as the primary task . Subjects were shown a memory set of either 2, 4, or 6 items followed by a memory probe. They had to decide if the probe was a member of the memory set and press the appropriate key on the computer keyboard as quickly as possible without making errors. Each subject was given 40 trials at each memory set size. The first 10 trials were practice. Half of the trials were positive probes and half were negative probes, all in random order. Response latencies associated with incorrect responses were disregarded. Total reaction time tells us how long it took for the subject to encode, search their working memory and make a decision as to whether or not the probe was in the memory set. Previous work shows that reaction time increases as set size increases, and the slope

of the line relating memory set size to response time is a measure of the rate of scanning working memory. If the slope of the line relating set size to response time is steeper at altitude than sea level, the conclusion would be that altitude impaired the rate of scanning working memory. If response latency is longer at altitude than control but the lines remain parallel, either encoding or decision has been affected. The study by Salthouse and Somberg (1982) is a good example of the application of the Sternberg task to study individual differences in working memory. This study used the Sternberg task to assess the effects of aging on information processing stages. Subjects were 13 males and 11 females between the ages of 18 and 28 and 12 males and 12 females between the ages of 64 and 81, all of whom reported to be in good health. The Vocabulary and Digit Symbol subsets of the Wechsler Adult Intelligence Scale-Revised were administered prior to the experiment. The memory scanning section of the study was performed on a computer and employed two 10-key pushbutton telephone keyboards. Subjects were presented with a memory set of 1 or 4 digits. Subjects were presented with a series of probe digits for each memory set size and asked to decide as quickly as possible if the probe was a member of the memory set and press the appropriate key on the computer. A response manipulation was used. In the simple response, subjects were told to press the a key on the right side of the keyboard if the probe was in the memory set and the "0" key on left side of the keyboard if the probe was not in the memory set. In the complex response, when the probe was not a member of the memory set subjects had to press the key on the left side of the keyboard corresponding to the probe number. Subjects were also tested under degraded probe conditions in which the target digits, which were made up of

approximately 20 dots, were superimposed by a random pattern of 20 dots. Each block consisted of 60 trials with the first 10 being practice. Results show main effects of age and all experimental factors. Age also interacted significantly with each of the other three factors, degradation, response type, and comparison set size. The results show that age has an effect in each of the three stages, stimulus encoding, internal comparison, and response preparation or execution, investigated in this study. Input effects are reflected in the results that show older adults are affected more by degradation than younger adults. Effects on the comparison stage are reflected in the results that show older adults have a greater increase in reaction time than younger adults as set size increases. Finally, the effects on the output stage are reflected in the results that show older adults have greater increases in response time and errors than younger adults when they change from a simple response to a complex one. The results also point to the assumption that degradation has a primary effect on the encoding stage and secondary effects on the comparison and response stages. If this is true, one can not be sure that the interaction of age and degradation is attributable to an age problem in the encoding stage. This study supports the hypothesis that age- related decrements in speed tasks cannot be located in one information processing stage.

The second task in the present experiment was a vigilance task. Subjects were shown 30 digits per min on a computer screen. When they saw an 8 following a 3, they responded by hitting the space bar. The task was performed for 30 min, and the data were collected for 6 blocks of 5 min. In each block, the number of errors of omission (failing to respond to a 3 - 8 pair), the response time to correct responses, and the number of errors

of commission (responding to something that was not a 3 - 8 pair), were recorded. The purpose of using this task was to have subjects perform a task similar to the pilot environment while flying, when a display has to be monitored for a long period of time and periodic responses need to be made. In our experiment, at the same time the subjects were doing the above task, each subject was also asked to attend to standard radio calls and answer to only their call sign. These 80 radio calls were prerecorded by a student in the Air Traffic Control program and had both high (at least 4 pieces of information to remember) and low (no more than 2 pieces of information to remember) memory loads. The radio calls were recorded approximately one every 20 s. Each subject was given two scores, one for the number of high load readbacks correct and one for the number of low load readbacks correct. These two tasks were chosen because they mimic the flying environment by having subjects attend to both visual and auditory stimulus. In a flying situation, a pilot would attend to aircraft instruments and the outside environment while listening to radio calls.

CHAPTER II

METHOD

Participants

Subjects were 72 volunteer students and flight instructors, 17 females and 55 males, from the Aerospace Science Department at the University of North Dakota, Grand Forks. They varied in the number of flight hours they have and in their experience in the hypobaric chamber, ranging from novice to highly experienced. They were required to either have or be working on their instrument rating and to have completed a course in Aerospace Aviation which included at least one ride in the altitude chamber. An examination of Table 1 indicates the number of subjects in each group and their average ages.

Apparatus

The hypobaric chamber at the Center for Aerospace Sciences at the University of North Dakota, Grand Forks was used for this study. The Sternberg task and the Vigilance task were both administered by an Apple IIe computer.

Materials

One of the tests subjects were administered was the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981) vocabulary subtest. This test consists of 35 words of increasing difficulty. Subjects are auditorially presented with each word and asked to verbally provide a short definition. Testing is discontinued after 5 consecutive

incorrect responses. Each item is scored according to guidelines provided in the WAIS-R manual, and responses may receive 0, 1, or 2 points. The maximum score possible on this measure is 70. The split-half reliability for the vocabulary subtest is .96

Another test was the Digit Span subtest from the Wechsler Memory Scale-Revised (WMS; Wechsler, 1987). This subtest consists of a sequence of digits that range from 2 to 8 digits in length. Subjects are required to listen to each sequence and repeat the sequence in the exact order in which it was presented (digits forward). There are 2 sequences presented at each length. In the second part of the test, subjects are required to repeat the digits in reverse order to that in which they were presented (digits backward). The test-retest reliability for the digit span subtest is .83.

The subjects also completed the Digit Symbol subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981). This subtest presents a subject with the digits one through nine. Each digit has a unique symbol corresponding to it. Below the digit-symbol key are 93 digits with spaces below them in which the subject draws the corresponding symbol. The subject is given 90 s to complete as many as possible as accurately as possible, moving sequentially through the test. A raw score of the number of symbols correctly transcribed in the 90 s is recorded, and this score could range from zero to 93. The test-retest reliability for the digit symbol subtest is .82.

The validity of the vocabulary, digit span and digit symbol subtests has been established in a variety of studies (Kaufman, 1990).

The subjects also completed the Vandenberg Mental Rotation Test (Vandenberg & Kuse, 1978). This test measures the ability to rotate three-dimensional objects in space.

Each subject is presented with two tests, each with ten items. The subject is given three minutes to complete each of the two sections. Both sections contain the same type of item. Each item presents the subject with a target figure created with ten cubes. Next to the target is an array of items, also made of ten cubes. Two of the items are identical to the target, but are rotated in space. Two of the items are dissimilar to the target. The subject's task is to choose the two identical items. The subject's score is based upon correctly identifying identical shapes, and one could score from zero to 40. To correct for random guessing, if a subject chooses two answers for one of the target items, but one answer is correct and one is wrong, the subject receives no points. One point is given if, for a target figure, only one answer is chosen, and the answer is correct, and two points are given if two items were chosen, and both are correct.

One more task completed before entering the chamber was the near-contrast sensitivity task. The test employed was the Vistech VCTS 6000 chart (Vistech Consultants, 1988) which has five rows of nine circular targets. Most targets contain lines which are drawn one of three ways, straight up and down, slanted to the right, or slanted to the left. The final target in each row is blank. The sensitivity varies from high contrast to low contrast as the rows move down the chart. Row A's sensitivity varies from 3 to 170 (1.5 cyces per degree [cpd]), Row B's from 4 to 220 (3 cpd), Row C's from 5 to 260 (6 cpd), Row D's from 5 to 170 (12 cpd), and Row E's from 4 to 90 (18 cpd). The chart is held 13 inches from the subject. Subjects determine if the target contains lines, and, if it does, what direction they are drawn. The subject's score is determined from the lowest

contrast he or she is able to discern and the number of targets correctly described for each row of the chart (A-E).

Finally, before entering the chamber, the height and weight of each subject was taken to determine a gross estimate of his or her physical fitness.

Procedure

Subjects were assigned to one of three groups based on the scores of the pretests in an attempt to equate the groups on their vocabulary and mental rotation tests. The motivation to match groups on these measures resulted from previous research that has demonstrated the relationship between vocabulary ability and cognitive performance (Hunt, 1975) and mental rotation ability and pilot performance (Petros, 1993). Then the group was tested at either 2,000 ft, 12,500 ft, or 15,000 ft. Subjects were tested in groups of up to 4 people. The group was put into the chamber and assigned his or her own computer station. We then began our ascent at a rate of 1,700 ft per min, the highest rate a University of North Dakota aircraft can climb at. Once the appropriate altitude was achieved, the experimenter began reading the instructions for the Sternberg memory task. Approximately 5 mins after reaching altitude, subjects began the task. The Sternberg memory scanning task was administered using an Apple IIe computer. In this task, memory sets of 2, 4, or 6 digits were shown on the computer screen. A varied memory set was presented for each target stimulus such that a different set of digits was used for each trial. After presentation of the memory set, a probe appeared on the screen. Subjects had to decide whether or not the probe was a member of the memory set of digits and respond as quickly as possible, without error, by pressing the appropriate key on the

computer keyboard. For each memory set size, half of the responses were positive and half were negative. The first 10 trials of a block were considered practice. All trials for one memory set size were completed before going on to the next block of 40 trials, for a total of 120 experimental trials. Subjects initiated a trial by pressing the space bar on the keyboard. The memory set then appeared on the screen and stayed in view until the subject pressed the space bar a second time. The memory set immediately disappeared, and an "X" appeared in the middle of the screen for 1 s after which it was replaced by the target probe. The subjects responded by pressing the "P" key if the probe was a member of the memory set (yes) or pressing the "Q" key if the probe was not a member of the memory set (no). A new trial was initiated by the subject by again pressing the space bar. The computer recorded how long the subject studied the memory set and the latency to respond to the probe.

In the final portion of this experiment, subjects did a divided attention task. One of the tasks was a vigilance task. Subjects were shown 30 digits per min on a computer screen. When they detected the number 3 followed by the number 8, they responded by pressing the space bar as quickly as possible. Subjects did 6 blocks. Each block was 5 min long and had ten 3 - 8 probes in it. If a response to an appropriate sequence was not made within 1500 ms, it was counted as an error. Three measures of performance were recorded, correctly detecting a target, time taken to respond to a target, and the number of responses made in error, to include errors of commission and errors of omission as well as late responses.

While subjects were performing this task, they were listening to prerecorded radio call which were recorded by a student in the Air Traffic Control program and consisted of both high and low memory loads. Gaps of time were recorded after each radio call to allow time for a verbal response. Each subject was put on headset, assigned a call sign, and instructed to recall and respond to a radio call only if his or her call sign was used. Subjects were provided with pencils and paper to write down any information they chose, just as they would in the aircraft.

Once the vigilance task was completed, the Sternberg task was re-administered using the same procedures as in the first administration.

CHAPTER III

RESULTS

Demographic Variables

In order to examine whether our groups were different on the variety of individual difference measures we obtained, a series of one-way analyses of variance were conducted on age, height, weight, number of flight hours, number of instrument hours, vocabulary scores, mental rotation scores, digit symbol scores, and digit span-forward and digit span-backward scores (see Table 1). The only significant difference observed was for age, $F(2,69)=3.17, p<.05$. A subsequent Tukey HSD revealed that the age at the altitude of 12,500 was significantly greater than the age at either 2,000 or 15,000. One extreme age score of 40 was removed from the group at 12,500 ft, and significant group differences in age were no longer significant, $F(2,68)=2.19, p>.05$. However, this person's data were included in all subsequent analyses reported.

Vigilance Data

The median response time for all correct responses to prime target pairs was computed for all six blocks of the vigilance task separately for each subject (see Table 2). Medians were used instead of means in order to reduce the contribution of extreme scores. These data were analyzed using a 3 (Altitude) x 6 (Blocks) mixed analysis of variance. The only significant effect observed in this analysis was a main effect of Blocks, $F(5, 305)=2.98$, $p<.01$. The Tukey HSD test revealed that response latencies for Block 1 were

Table 1

Means and Standard Deviations for Demographic Variables

Measure	Altitude 2,000	12,500	15,000	F
N	25	23	24	
Age (years)	21.8 (1.73)*	23.7 (4.16)	22.1 (1.91)	3.17
Height (inches)	70.8 (3.96)	70.6 (3.56)	69.9 (2.84)	0.46
Weight (pounds)	173.7 (27.01)	170.8 (32.96)	177.2 (30.53)	0.27
Flight Hours	346.2 (354.1)	533.9 (664.2)	487.8 (551.8)	0.81
Instrument Hours	52.1 (42.7)	53.4 (46.0)	71.6 (66.4)	1.03
Vocabulary	49.0 (6.16)	51.3 (6.82)	53.3 (7.29)	2.51
Mental Rotation	21.9 (8.76)	19.8 (8.85)	19.3 (5.95)	0.76
Digit Symbol	73.0 (11.44)	72.7 (8.92)	73.8 (10.10)	0.07
Digit Span (Forward)	10.0 (1.91)	8.9 (2.00)	9.4 (2.48)	1.54
Digit Span (Backward)	8.6 (2.41)	8.1 (1.50)	7.8 (2.89)	0.82

*Note: Standard deviations appear in parentheses

Table 2

Median Response Latencies (ms) as a Function of Altitude and Blocks for the Vigilance Task

	Block					
Altitude	1	2	3	4	5	6
2,000						
	365 (104)*	387 (125)	403 (161)	402 (156)	441 (212)	444 (200)
12,500						
	377 (114)	427 (138)	391 (110)	387 (118)	382 (88)	382 (122)
15,000						
	382 (105)	405 (133)	444 (189)	464 (164)	447 (181)	452 (175)

*Note: Standard deviations appear in parentheses

significantly faster than all of the other Blocks and latencies for Block 2 were significantly faster than Block 5 and Block 6.

The slope and intercept of the lines relating response latencies to block were computed for each subject for all correct responses to prime target pairs (see Table 3). These data were analyzed using a one way analysis of variance separately for the slopes and intercepts. The analysis revealed no significant effects.

The number correct for responding to 3 - 8 pairs (out of 10) was computed for all six blocks of the vigilance task separately for each subject (see Table 4).

Table 3

Slopes and Intercepts of the Median Response Latencies for the Vigilance Task

Altitude	Slope (ms/block)	Intercept (ms)
2,000		
	15.868	351
	(32.895)*	(94.5)
12,500		
	-3.225	402
	(19.595)	(120.3)
15,000		
	14.298	382
	(33.535)	(140.7)

*Note: Standard deviations appear in parenthses

Table 4

Mean Number Correct as a Function of Altitude and Blocks for the Vigilance Task

	Block					
Altitude	1	2	3	4	5	6
2,000						
	7.778	8.455	8.182	7.864	7.955	9.455
	(1.478)*	(0.963)	(1.468)	(1.490)	(1.588)	(0.800)
12,500						
	8.444	7.833	8.056	8.000	8.667	9.167
	(1.247)	(1.098)	(1.434)	(1.815)	(1.328)	(0.924)
15,000						
	7.333	7.458	7.917	7.542	7.625	8.792
	(1.857)	(2.085)	(1.501)	(1.382)	(1.663)	(1.250)

*Note: Standard deviations appear in parentheses

These data were analyzed using a 3 (Altitude) x 6 (Blocks) mixed analysis of variance. The analysis revealed no significant effects. In order to establish the stability of these results, given the highly accurate response rates, a similar analysis of the square root transformation of the number correct to 3 - 8 pairs also resulted in no significant effects.

The slope and intercept of the line relating the number of correct responses to prime target pairs was computed for all six blocks of the vigilance task separately for each subject (see Table 5). These data were analyzed using a one way analysis of variance separately for the slopes and intercepts. The analysis revealed no significant effects. The number of errors of commission, defined as responding to prime only (only a 3) or target only (only an 8), was computed for all six blocks of the vigilance task separately for each subject (see Table 6). These data were analyzed using a 3 (Altitude) x 6 (Blocks) mixed analysis of variance. The analysis revealed no significant effects.

Readback Data

The proportion of readbacks correctly recalled was scored blind by two independent raters (see Table 7). The percent of agreement between raters was determined for each recall protocol, with the agreement ranging between 81.30% to 100.00% with a mean level of agreement of 96.89%.

Table 5

Means Slopes and Intercepts of the Number of Correct Responses for the Vigilance Task

Altitude	Slope (number correct/block)	Intercept (number correct)
2,000	0.188 (0.304)*	7.62 (1.40)
12,500	0.173 (0.221)	7.76 (1.12)
15,000	0.212 (0.270)	7.04 (1.58)

*Note: Standard deviations appear in parentheses

Table 6

Mean Number of Errors of Commission as a Function of Altitude and Blocks for the Vigilance Task

	Block					
Altitude	1	2	3	4	5	6
2,000	0.182 (0.395)*	0.364 (0.581)	0.273 (0.550)	0.227 (0.429)	0.812 (0.501)	0.227 (0.528)
12,500	0.333 (0.594)	0.222 (0.548)	0.111 (0.323)	0.278 (0.461)	0.111 (0.323)	0.111 (0.323)
15,000	0.208 (0.415)	0.333 (0.482)	0.125 (0.338)	0.125 (0.448)	0.208 (0.415)	0.333 (0.565)

*Note: Standard deviations appear in parentheses

Table 7

Mean Number Correct for Readbacks as a Function of Load and Altitude

	Memory Load	
Altitude	High	Low
2,000	63.40 (19.5)*	90.93 (11.64)
12,500	48.08 (22.76)	91.13 (8.62)
15,000	46.90 (16.00)	92.12 (9.94)

*Note: Standard deviations appear in parentheses

The scores were subjected to a 2 (Memory Load) x 3 (Altitude) mixed analysis of variance. A significant main effect of memory load was observed, $\underline{F}(1,55)= 255.45$, $\underline{p}<.01$, indicating that readback scores were significantly worse for high memory loads (mean = 52.80 %) as compared to low memory load (mean = 91.39%). A significant interaction effect between Memory Load and Altitude was also observed, $\underline{F}(2,55)=5.64$, $\underline{p}<.01$. A subsequent Tukey HSD revealed that for high memory loads, recall at both 12,500 ft (mean = 48.08%) and 15,000 ft (46.90%) was significantly worse than at 2,000 ft (63.42%), while at the low memory load no significant difference in recall was observed across the three altitudes.

Sternberg Data

The median response time was computed for each test time by set size by decision condition separately for each subject (see Table 8 and Table 9).

Table 8

Median Response Latencies (ms) as a Function of Test Time, Set Size, and Decision at Time 1 for the Sternberg Task

	Set Size					
	Yes			No		
Altitude	2	4	6	2	4	6
2,000	613 (144)*	760 (153)	853 (212)	669 (138)	788 (172)	1065 (314)
12,500	641 (150)	759 (173)	917 (234)	696 (153)	834 (213)	1021 (279)
15,000	637 (159)	735 (155)	837 (161)	733 (219)	775 (188)	908 (216)

*Note: Standard deviations appear in parentheses

Response latencies associated with errors were removed for these calculations. These data were subjected to a 3 (Altitude) x 2 (Time of Testing) x 3 (Set Size) x 2 (Decision) mixed analysis of variance. A significant main effect of Time of Testing was observed, $F(1,69)=93.96$, $p<.01$, indicating that response latencies were significantly longer at the first testing time (mean = 790 ms) as compared to the second testing time (mean = 680

ms). A significant main effect of Set Size was also observed, F(2,138)=144.66, p<.01. A subsequent Tukey HSD revealed that response latencies significantly increased across all set sizes, with the set size of 6

Table 9

Median Response Latencies (ms) as a Function of Test Time, Set Size, and Decision at Time 2 for the Sternberg Task

	Set Size					
	Yes			No		
Altitude	2	4	6	2	4	6
2,000	537 (102)*	637 (122)	705 (196)	586 (115)	751 (178)	820 (262)
12,500	582 (117)	663 (162)	771 (217)	640 (139)	747 (213)	942 (354)
15,000	564 (126)	665 (144)	741 (209)	654 (208)	744 (205)	852 (250)

*Note: Standard deviations appear in parentheses

(mean = 1737 ms) being the slowest, followed by the set size of 4 (mean = 1476), then the set size of 2 (mean = 1257). A significant main effect of Decision was also observed, F(1,69)=52.82, p<.01, indicating that response latencies were significantly longer for negative responses (mean = 789.6 ms) than for positive responses (mean = 700.2 ms). A significant interaction effect between Time of Testing and Set Size was also observed,

F(2,138)=5.18, p<.01, (see Table 10). A subsequent Tukey HSD revealed that response latencies decreased for each set size from the first testing time to the second testing time with the largest effect for the set size of 6. A significant interaction effect between Set Size and Decision was also observed, F(2,138)=8.89, p<.01, (see Table 11).

Table 10

Interaction Effect of Time of Testing and Set Size for the Sternberg Task

	Set Size		
Testing Time	2	4	6
First	664.2	774.7	933.1
Second	593.1	700.8	803.7
Difference	71.1	73.9	129.4
Percent Difference	10.7	9.54	13.86

Table 11

Interaction Effect of Set Size and Decision for the Sternberg Task

	Set Size		
Decision	2	4	6
Yes	595.1	702.7	802.8
No	662.2	772.7	934.1
Difference	67.1	70.0	131.3
Percent Difference	10.1	9.06	14.06

A subsequent Tukey HSD revealed that response latencies were significantly smaller for positive than negative decisions at all set sizes, but the largest effect was observed for the

set size of 6. A significant four-way interaction between Altitude, Time, Set Size, and Decision was also observed, $\underline{F}(4,138)=4.01$, $\underline{p}<.01$ (see Figure 1 and Figure 2).

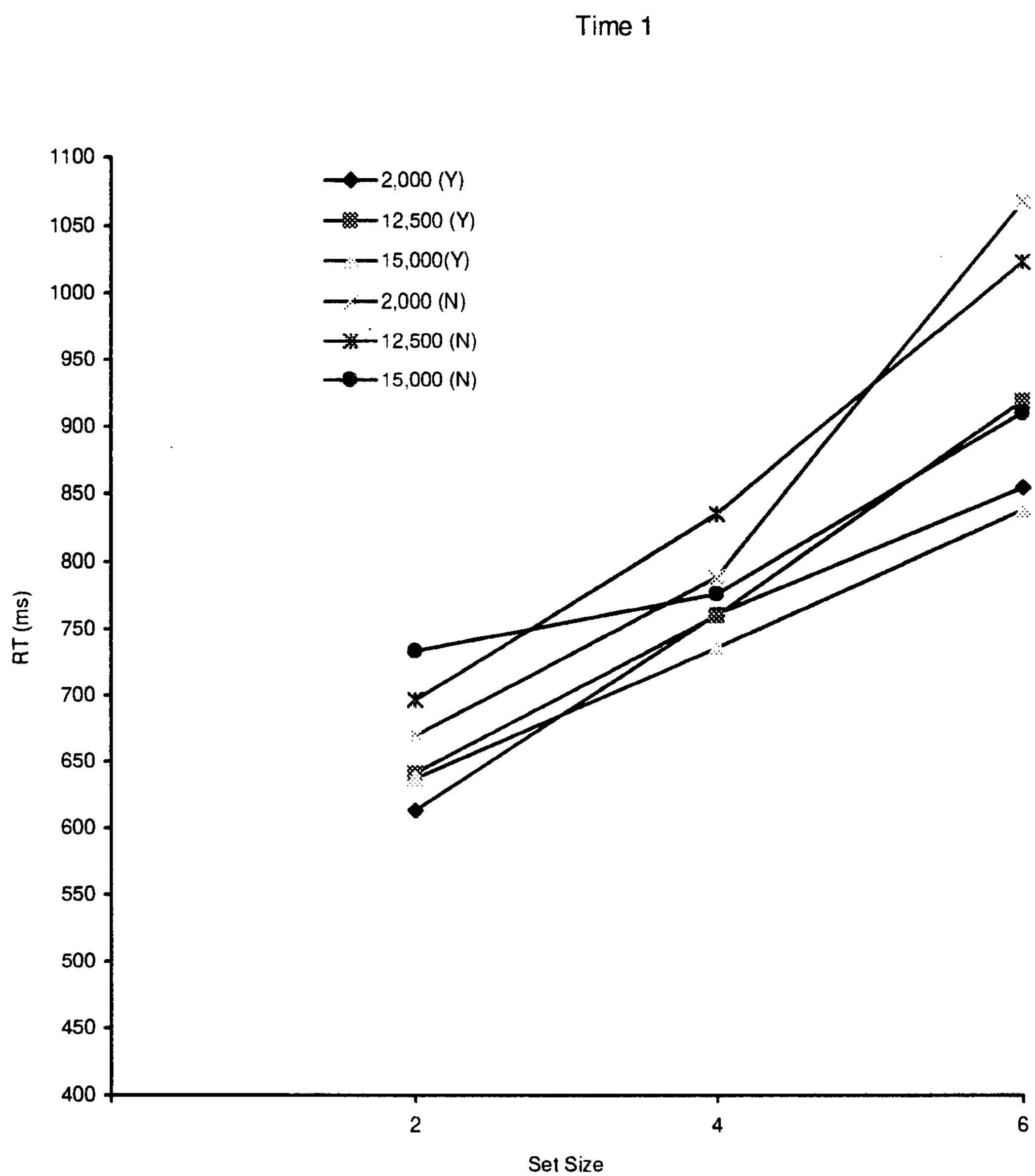

Figure 1. Response latencies for each of the three altitudes at Time 1, broken down by Set Size and Decision.

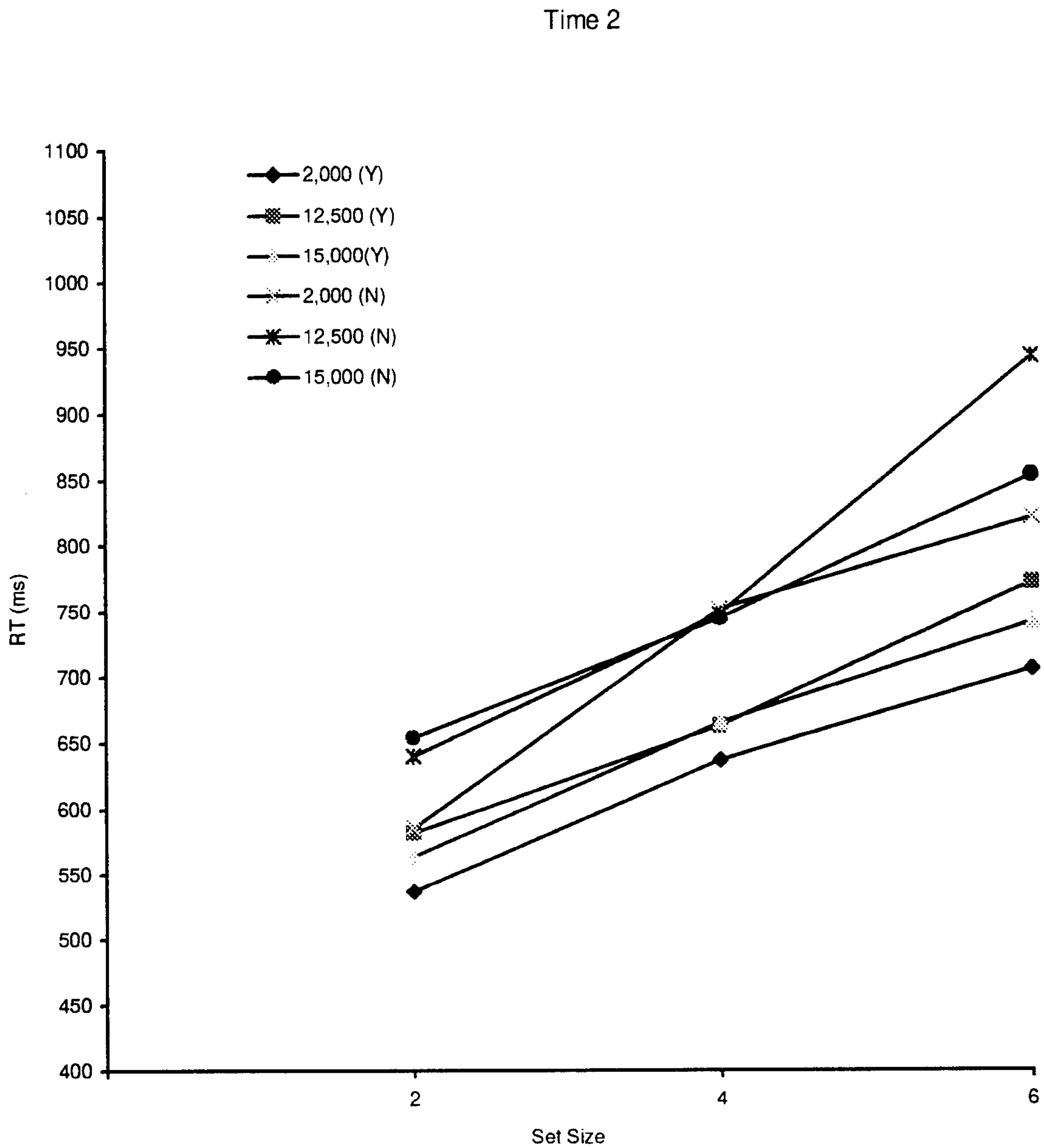

Figure 2. Response latencies for each of the three altitudes at Time 2, broken down by Set Size and Decision.

To further clarify this interaction, a separate analysis was performed for Time 1 and Time 2 using a 3 (Altitude) x 3 (Set Size) x 2 (Decision) mixed analysis of variance. At Time 2, no significant effects involving altitude were observed. However, at Time 1 a significant interaction of Altitude x Set Size x Decision was observed, $\underline{F}(4,138)=4.09$, $\underline{p}<.01$. A subsequent analysis of this 3-way interaction revealed for positive responses at set size 6, response latencies were significantly larger for 12,500 as compared to 2,000 and 15,000. The subsequent analysis of negative responses revealed significant differences in response latencies at all 3 set sizes. At set size 2, 15,000 was significantly larger than 2,000. At set size 4, 12,500 was significantly larger than 15,000. At set size 6, both 2,000 and 12,500 were significantly larger than 15,000.

The proportion of errors was computed for each test time by set size by decision separately for each subject (see Table 12 and Table 13).

These data were subjected to a 3 (Altitude) x 2 (Time of Testing) x 3 (Set Size) x 2 (Decision) mixed analysis of variance. A significant main effect of Time of Testing was observed, $\underline{F}(1,69)=6.13$, $\underline{p}<.01$, indicating that the error rate was significantly higher for Time 1 (mean = .050) than for Time 2 (mean = .040). A significant main effect of Decision was also observed, $\underline{F}(1,69)=24.75$, $\underline{p}<.01$, indicating that error rate was significantly higher for positive responses (mean = 0.056) than for negative responses (mean = 0.033). A significant interaction effect between Set Size and Decision was observed, $\underline{F}(2,138)=6.81$, $\underline{p}<.01$ (see Table 14). A subsequent Tukey HSD revealed negative responses had significantly more errors than positive responses and the effect was largest for the set size of 6. The Tukey HSD also revealed that for positive responses,

Table 12

Mean Proportion of Errors as a Function of Altitude, Set Size and Decision at Time 1 for the Sternberg Task

	Set Size					
	Yes			No		
Altitude	2	4	6	2	4	6
2,000	0.037 (0.058)*	0.067 (0.069)	0.093 (0.092)	0.043 (0.054)	0.035 (0.058)	0.024 (0.038)
12,500	0.064 (0.086)	0.035 (0.040)	0.072 (0.083)	0.038 (0.060)	0.038 (0.052)	0.043 (0.062)
15,000	0.042 (0.051)	0.061 (0.068)	0.086 (0.080)	0.053 (0.073)	0.047 (0.054)	0.017 (0.045)

*Note: Standard deviations appear in parentheses

the error rate for the set size of 6 was significantly larger than for the set size 4 and 2. There were no significant differences across set sizes for negative responses.

Individual slopes and intercepts were computed for each subject at each altitude (see Table 15). These data were subjected to a 3 (Altitude) x 2 (Time of Testing) mixed analysis of variance. Analysis of the intercepts revealed no significant observations. Analysis of the slopes revealed a significant main effect of Time of Testing, $\underline{F}(1,69)=6.81$, $\underline{p}<.05$, indicating a larger slope at Time 1 (mean = 134.5) than Time 2 (mean = 105.3). To further understand the effect of time, an analysis was run for the slopes separately at

Table 13

Mean Proportion of Errors as a Function of Altitude, Set Size, and Decision at Time 2 for the Sternberg Task

	Set Size					
	Yes			No		
Altitude	2	4	6	2	4	6
2,000	0.040 (0.082)*	0.051 (0.075)	0.067 (0.090)	0.024 (0.042)	0.027 (0.054)	0.027 (0.051)
12,500	0.046 (0.062)	0.029 (0.053)	0.046 (0.051)	0.023 (0.038)	0.020 (0.047)	0.029 (0.056)
15,000	0.064 (0.072)	0.047 (0.050)	0.064 (0.085)	0.033 (0.059)	0.050 (0.066)	0.031 (0.052)

*Note: Standard deviations appear in parentheses

Table 14

Interaction Effect of Set Size and Decision for the Sternberg Task

	Set Size		
Decision	2	4	6
Positive	0.049	0.049	0.072
Negative	0.036	0.036	0.028
Difference	0.013	0.013	0.044
Percent Difference	26.5	26.5	61.1

Table 15

Mean Slopes and Intercepts as a Function of Altitude and Time of Testing for the Sternberg Task

	Slope (ms/set size)		Intercept (ms)	
Altitude	Time 1	Time 2	Time 1	Time 2
2,000				
	159.0 (98.7)*	100.5 (73.9)	473.3 (167.5)	471.6 (86.3)
12,500				
	150.3 (89.3)	122.8 (99.0)	510.3 (160.0)	478.6 (128.4)
15,000				
	93.8 (87.4)	93.7 (79.5)	583.3 (246.7)	515.9 (162.2)

*Note: Standard deviations appear in parentheses

Time 1 and Time 2. No significant effect were observed at Time 2, $\underline{F}(2,69)=.76$, $\underline{p}>.05$. However, at Time 1 there was a significant effect between groups, $\underline{F}(2,69)=3.57$, $\underline{p}<.05$. A subsequent Tukey HSD revealed that the slope for subjects at 2,000 ft was significantlylarger than the slope for subjects at 15,000 ft while all other pairwise comparisons were not significant.

Tasks that utilize reaction time methodologies are based upon the assumption that response latencies and error rates are positively correlated. Failure for this to occur would result in difficulty in interpreting the results and be suggestive of a speed-accuracy tradeoff in the data. In order to examine this question, the correlation between the median

response latencies and error rate was calculated over all observations and was not observed to be significant, $r(862)=.0526$, $p>.05$. In addition, this correlation computed separately with each group was $r(298)=.0170$, $r(274)=.0625$, and $r(286)=.0958$, for altitudes 2,000 ft, 12,500 ft, and 15,000 ft, respectively. None of these correlations approached conventional levels of significance. In order to more closely examine the potential influence of speed-accuracy tradeoffs in the data, a Pearson correlation was computed separately for each subject between the reaction time and error data. These correlations were based upon 12 observations per subject (i.e., Time of Testing by Set Size by Decision). An examination of these correlations revealed that 14 subjects had positive correlations in the 2,000 ft group, 13 had positive correlations in the 12,500 ft group, and 11 had positive correlations in the 15,000 ft group (see Table 16). A 3 (Altitude) x 2 (Time of Testing) analysis of variance was conducted on the slopes and intercepts of only subjects who had positive correlations. For the slope of the lines, the analysis revealed a significant interaction effect between Altitude and Time of Testing, $F(2,35)=3.39$, $p<.05$. A subsequent Tukey HSD revealed no significant effects at Time 2. However, at Time 1, the slope of the line at 2,000 ft was significantly larger than at 15,000 ft but not significantly larger than at 12,500 ft. When looking at the overall slopes for Time 1 compared to Time 2, the slope of the line for 2,000 ft was the only one that decreased significantly (see Table 17)

For the intercept of the lines, a significant main effect of Time of Testing was observed, $F(1,35)=6.38$, $p<.05$. The intercept for Time 1 (mean = 548.56) was significantly higher than the intercept for Time 2 (mean = 491.53). A 3 (Altitude) x 2

Table 16

Mean Slopes and Intercepts for Subjects with Positive Correlations of Response Latencies and Error Rates as a Function of Altitude and Time of Testing for the Sternberg Task

	Slope (ms/set size)		Intercept (ms)	
Altitude	Time 1	Time 2	Time 1	Time 2
2,000				
	160.9	93.6	487.9	501.0
	(84.5)*	(90.1)	(127.3)	(83.4)
12,500				
	140.1	129.1	554.4	468.8
	(94.1)	(100.7)	(163.7)	(101.3)
15,000				
	77.8	107.5	618.9	506.3
	(52.8)	(91.9)	(200.3)	(182.1)

*Note: Standard deviations appear in parentheses

Table 17

Interaction Effect of Altitude and Time of Testing for Subjects with Positive Correlations of Response Latencies and Error Rates for the Sternberg Task

	Altitude		
Time	2,000	12,500	15,000
1	160.91	140.14	77.78
2	93.67	129.14	107.52
Difference	67.24	11.00	29.74
Percent Difference	41.79	7.85	38.23

(Time) analysis of variance was conducted on the slopes and intercepts of only subjects who had both a positive reaction time-error correlation and slopes greater than zero. This criterion resulted in the deletion of 1 further subject from the 15,000 ft group (see Table 18).

Table 18

Mean Slopes and Intercepts for Subjects with Both Positive Slopes and Positive Correlations of Response Latencies and Error Rates for the Sternberg Task

	Slope (ms/set size)		Intercept (ms)	
Altitude	Time 1	Time 2	Time 1	Time 2
2,000	160.9 (84.5)*	93.7 (90.1)	487.9 (127.3)	501.0 (83.4)
12,500	140.1 (94.1)	129.1 (100.7)	554.4 (163.7)	468.8 (101.3)
15,000	85.8 (48.1)	106.0 (96.7)	612.1 (209.8)	517.9 (187.5)

*Note: Standard deviations appear in parentheses

Analysis of the slopes revealed no significant effects. Analysis of the intercepts revealed a significant main effect of Time of Testing, $\underline{F}(1,34)=5.08$, $\underline{p}<.05$. The intercept at Time 1 (mean = 544.8) was significantly greater than the intercept at Time 2 (mean = 494.3).

CHAPTER IV

DISCUSSION

The main finding of this study was the significant effect of altitude on recall of readbacks of a high memory load. Since there were no significant findings for low memory loads, we can conclude the difference for high memory loads was not due to some physical factor such as diminished auditory sensitivity. It is interesting that, even at moderate altitudes, differences were observed only for readbacks of high memory load. This suggests that, at altitude, working memory was exceeded for the readbacks requiring a larger amount of information to be recalled, but working memory was not exceeded for the same amount of information at the control altitude. Information processing theorists have argued that humans have a limited pool of cognitive resource to process information. Many factors, such as alcohol, fatigue, and circadian variations (Petros, 1985; Petros, 1990), can influence the amount of cognitive resources available at any given time to process information. The results of the readback task in the present study indicate that altitude may also influence the amount of cognitive resources available to process information. This could lead to dangerous situations such as missed indications of engine problems, incorrect reading of instruments, and added difficulty in handling unusual situations such as extreme weather conditions or emergencies. The present study suggests that civil aviators may be more susceptible to accidents while flying without supplemental oxygen at, or even after flying at, altitudes the Federal Aviation Administration finds

acceptable. If the effects last into descent and approach, a very demanding time, even more problems could be created.

Performance on the Vigilance task was not affected by altitude. This suggests that altitude alone does not impair the basic skills of monitoring and attending to a single channel of information for a sustained period of time, in this study, 30 min. Typically, when navigating the aircraft, pilots are monitoring several channels of information simultaneously while also monitoring radio calls. Possibly, the readback deficits observed in the present study would have been magnified if the vigilance task required the simultaneous allocation of attention to multiple channels of information.

The results of the Sternberg task were contrary to expectation and difficult to interpret. The longer response latencies and greater error rates over time, for larger set sizes, and for negative versus positive responses and their interactions agreed with past research. However, no important effects involving altitude were found. The effects that were significant were not consistent, with subjects sometimes performing best at 15,000 ft, sometimes at 12,500 ft, and sometimes at 2,000 ft. The differing results from the Sternberg task and the readback task may reflect the use of different cognitive processes. One channel of input, as in the Sternberg task, may not be affected by hypoxia at moderate altitudes but multiple inputs, such as the combination of the visual vigilance task and the auditory readback task, may be. This latter task, using simultaneous channels of input, is more like that experienced in the pilot environment where radios, instruments, and other inputs must be constantly monitored and attended to.

There are some possible limitations to this study. First of all, the Vigilance task may have been too easy. In the flying environment, pilots must monitor many things, including flight instruments, engine instruments, and 1 or more radios. Future research may consider a more difficult monitoring task, such as computerize tracking task. A second limitation relates to generalizability. Subject in this study had a relatively low number of flight hours, an average of less than 550 hr., so the data may not apply to those with more experience, such as airline pilots and military pilots. However, the results would generalize to the population of civilian aviators without much experience.

Future research can go in many directions. One possibility is looking at factors that might exacerbate cognitive deficits at moderate altitudes such as circadian rhythms, hangover effects, antihistamine usage, and fatigue. Another would be to look at how long effects from exposure to moderate altitudes persists, allowing predictions about pilot performance in one of the most critical and dangerous phases of flight, landing. Research could also search for a more exact altitude for such cognitive deficits. Replication of this study using lower altitudes such as 10,000 ft or even 8,000 ft could reveal interesting findings and would directly relate to Federal Aviation Administration policy.

There are many possibilities in this area of research and the surface has barely been scratched. Not only is the field wide open, it is also very important. This research could help to avoid future aircraft incidences and possibly even save lives.

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